Transglobal Vehicular Solutions

Project Final Report
MASE 319: Introduction to Naval Architecture
December 9, 2015

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Abstract (Written by Zachary Gonzales)

This report covers the comprehensive concept design of a reliable, efficient, and environmentally friendly Panamax Ro-Ro ship optimized for transatlantic voyages. The client (Rotto Nordic Lines) specified minimum cargo capacities and provided vessel dimensions that were not to be exceeded in order to traverse a variety of ports, terminals, and routes. The design was an iterative process and loosely involved five main subjects for analysis: Hull form, vessel structure, hydrostatics, hydrodynamics, and finally vessel powering.

Rotto Nordic Lines' fleet is aging and this design solution provides a viable replacement for their current vessels. The main challenge was finding vessel dimensions that would accommodate the cargo capacity requirements but did not exceed the maximum dimensions.

The result is *TVS Caitlyn*, a Panamax Ro-Ro vessel that meets all of the client's specifications. The table below presents the end solution and shows that the tasks associated with conceptual vessel design were completed successfully.

Length PP	**180**	**[m]**
Length OA	**185**	**[m]**
Breadth	**28**	**[m]**
Draft	**7**	**[m]**
Air Draft	**37**	**[m]**
Displacement	**29,442**	**[tonnes]**
$\overline{GM}$ at full load capacity	**2.168**	**[m]**
Service Speed	**21**	**[kn]**
Propulsion	**2 MAN B&W 6S60ME slow speed diesel engines**	
Fuel	**Bunker fuel while underway, diesel when in port**	
Number of Decks	**7 watertight + weather deck = 8**	
TEU Capacity	**1080**	**[TEU]**
Automobile Capacity	**1702**	**[vehicles]**
Internal On/Offloading	**MacGregor watertight hydraulic lift ramps**	
External On/Offloading	**TTS Marine wire operated lift ramp systems**	
Manning	**12**	

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1. Introduction (Written by William Foy)

To produce a quality design, all design parameters as well as ABS specifications were met throughout each phase of the solution. To complete a project of such magnitude, TVS assembled a team of its finest engineers: Lauryn Emmitte, William Foy, Zachary Gonzales, Micah Thoms, and Christopher Williams.

Following the successful solution of the client's design specifications, a breakdown of TVS *Caitlyn*'s capabilities are subsequently given:

TVS *Caitlyn* is capable of housing 1808 automobiles and 1189 TEUs at maximum capacity, though to maintain the design draft of 7 meters, it must only carry 1702 automobiles and 1080 TEUs. Exceeding these values is possible, as the vessel is watertight up to 12 meters, but the ship must comply with preordained values. The vessel possesses four decks with the ability to store TEUs as well as heavy machinery, and seven total watertight decks capable of housing automobiles.

All decks are equipped with hydraulic locking ramps, which promote ease of access between decks, as well as retractable bulkheads, which allow for maximum loading capacity, in addition to greatly increased stability of the vessel as a whole.

Caitlyn is fully capable of transporting said cargo from the port of Gothenburg to Galveston in eleven days as specified by the client, with seven hours to spare. She accomplishes this task by following the shortest, safest route between the two ports.

She was produced by and registered in the United States of America, and classed by the American Bureau of Shipping as a Group 1 Roll-on-Roll-off vessel.

2. General Solution to the Design

2.1. Parent Ship: The Corona Seaways (Written by Lauryn Emmitte)

The beginning stages of this project required preliminary research of roll on roll off vessels. After the investigation of several ships, the DFDS *Corona Seaways* was chosen as the parent ship. It was selected due to the fact that it was similar to the given maximum parameters and has the capability of transiting through the Panama Canal. Although the final design was based off of multiple vessels, TVS decided to make its design dimensions primarily similar to the *Corona Seaways.* Table 1 shows the specification comparison between DFD's *Corona Seaways* and Transglobal Vehicular Solutions' *Caitlyn.*

Table 1: Specification Comparison

Details	*Corona Seaways*	*Caitlyn*
LOA (meters)	187	185
Beam (meters)	26.5	28
Draft (meters)	6.8	7
Speed (knots)	20	21
L/B Ratio	7.1	6.6
Δ (ton)	33,697.40	32,260
Decks	4	8
Passengers	12	12

Further explanation on how TVS came to the details such as final displacement and number of decks can be seen in the following paragraphs.

2.2 Design Solutions (Written by Lauryn Emmitte)

Upon being given the task of building a Ro-Ro, a strategy of how to do this had to be implemented. A breakdown of this process can be seen in Figure 1. It is a general overview of the plan to tackle the design procedure.

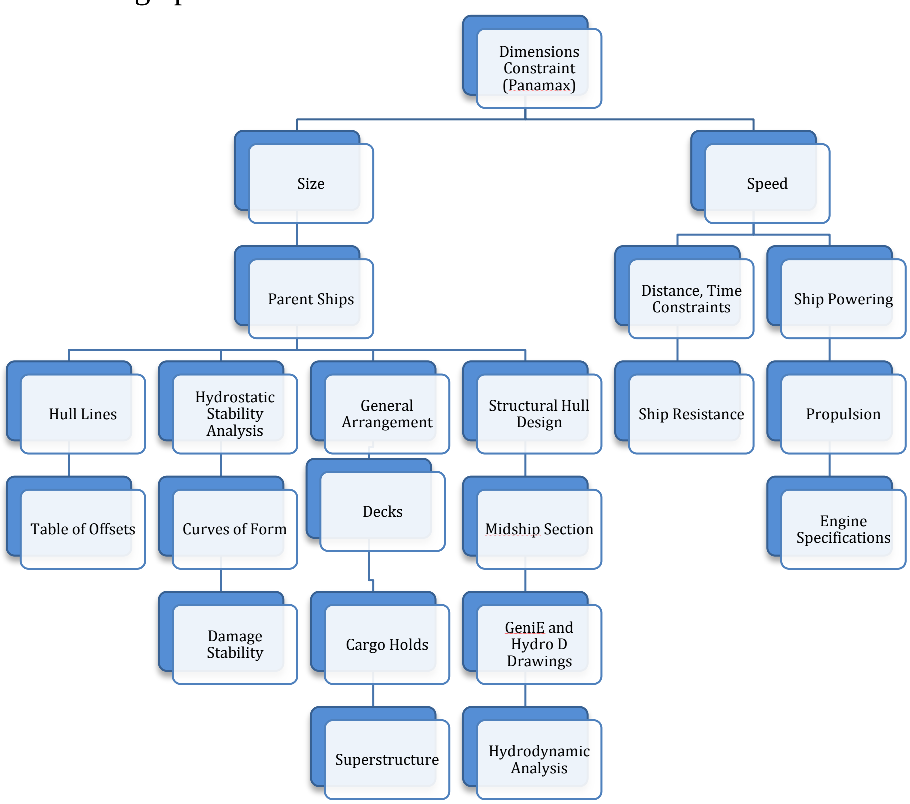

Figure 1: Design Strategy

Knowing that the vessel has to transit through the Panamal Canal was one of the first considerations in the design process. This put constraints on the size of the ship. After establishing a the length, breadth, and design draft, which was based off of the parent ship, the hull lines could be constructed. By drawing these, the table of offsets could also be extracted. From there, hydrostatic analysis, stability, arrangements, and structural details were completed.

Once deciding on basic dimensions such as length as breadth, the speed had to be determined. An online ship speed calculator from the Marine Vessel Traffic website could be used for this. By entering the start and end points of the voyage, the website calculated the speed necessary to travel from port to port. Figure 1 shows the results of a vessel with the requirements of sailing from the Port of Gothenburg to the Port of Galveston. By accomplishing this, a ship resistance as well as ship powering and engine specifications were determined.

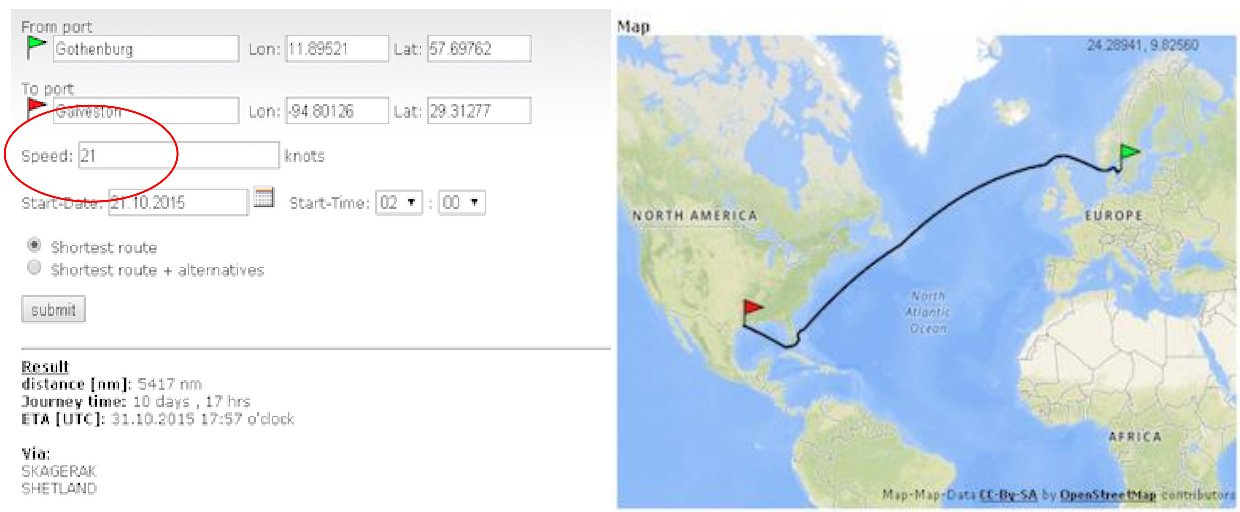

Figure 2: Ideal Ship Speed

As seen in Figure 1, the ideal speed of the vessel is 21 knots. This puts the voyage at 10 days, 17 hours, and travelling a total of 5,417 nautical miles. Once these initial parameters were established, further design considerations could be implemented.

2.3 Concept Solution (Written by Chris Williams and Micah Thoms)

In the design solution, many factors have been taken into consideration. TVS-RORO-1 is designed with an overall length of 185 meters, a length between perpendiculars of 180 meters, and a design draft of 7 meters. These dimensions allow for transit through the Panama Canal.

The vessel is designed in a group one style. The superstructure and bridge are in the forward-most part of the ship. This superstructure placement allows for TEUs to be stacked aft of the superstructure at the maximum allowed height. With this placement, the crew has full visibility without impedance from the cargo. Additionally, this superstructure placement allows the crew to feel the full effect of the sea state. The crew can change heading and course to preserve the stability of the vessel and cargo therein. Bridge wings can extend to 2 meters on either side. Bridge wings allow the crew to observe aft, and to pull in and out of port more readily without the use of tugs or external sources. There are 5,000 cubic meters of livable space in the superstructure. This space can accommodate meeting rooms, a galley, gym space, state rooms, and other crew accommodations.

The cargo offloading and on loading operations will make use of interior ramps, fixed ramps, one external-aft-heavy-load-ramp, and one light-load-amidships-ramp. The primary ramp systems on the interior of the vessel make use of chain driven or hydraulic ramps in the car decks. As shown in Figure 1, there are two ramp systems on port side, and two ramp systems on starboard side. During offloading and on loading, the ramps are lowered eight degrees to create a continuous flow of traffic from the lowest car deck to the TEU weather deck. When a car deck is full, the ramps for that specific deck are raised to allow additional cargo to be secured to them. The truck deck contains a fixed ramp system due to the overhead height in that deck. The aft ramp is affixed to the stern of the vessel. It folds about its axis to allow for stowage during transit. The interior ramps in the aft portion of the vessel originate at the main aft ramp.

The TVS *Caitlyn* is designed to have four car decks, two car/TEU decks, a TEU/heavy equipment deck, and additional TEUs on the weatherdeck. From these eight decks, seven will be watertight in order to protect the cargo. The dimensions for spacing the vehicles and TEU containers were based on the largest Volvo automobiles and construction equipment published on Volvo’s website.

She has two external ramps for loading and unloading of the vessel. One is located in the stern, (Figure 3), and will be capable to move large machinery. The other ramp is located amidship (Figure 4), and will aid in the unloading of vehicles. TTS Marine ASA was contracted to build the two external ramps for the TVS *Caitlyn*.

Figure 3: Aft External Ramp

Figure 4: Side External Ramp

Internally, there will be ramps on both port and starboard sides of the vessel. This will expedite the loading and unloading of the vessel and decrease time in port. MacGregor was contracted to install the internal ramps because of the unique design of the ramps, (Figure 5). These ramps will be hydraulically moved and are able to be locked by a pin, which allows for each ramp to sustain a load during the voyage, (Figure 6).

The ramps may be unhinged to act as a lift to move cargo from deck to deck. When fully locked in the upright positions the deck ramps are water tight in case the vessel were to take on water.

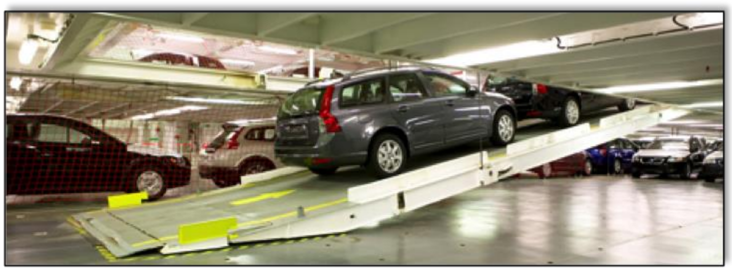

Figure 5: Internal Ramps

Figure 6: Double Hinged Internal Ramps

Finally, the bulkheads for the TVS Caitlyn will be fitted with a sliding link door system designed by TTS Marine ASA, (Figure 7). This will allow for the unimpeded movement of cargo during loading and unloading but when underway be sealed bulkheads to prevent the flooding of multiple compartments. This will be advantageous in respect to damage stability because this will greatly limit the amount of water taken on when damaged and allow the vessel to continue sailing to a near port to be repaired.

Figure 7: Sliding Bulkhead Solution

TVS Caitlyn has a preliminarily designed engineering and auxiliary space in the bottom deck of the ship. With a calculated deck to overhead height of 3.59 meters, all of the engineering equipment, auxiliary power equipment, ventilation equipment, and tanks will be placed within. These tanks are for fuel and ballast water to account for trim and list. Exhaust shafts will extend from the engineering space, through the allotted space in the vehicle decks and dissipate at the weather decks. Ventilation ducts will originate at the ventilation equipment and be distributed throughout the vehicle decks to meet the air exchange requirements. Additionally, a bulbous bow is incorporated into the design and will eventually house bow thrusters. Bow thrusters will allow the vessel to berth without the use of tugboats or pier assistance. These concept solutions can be seen in Figure 8 below.

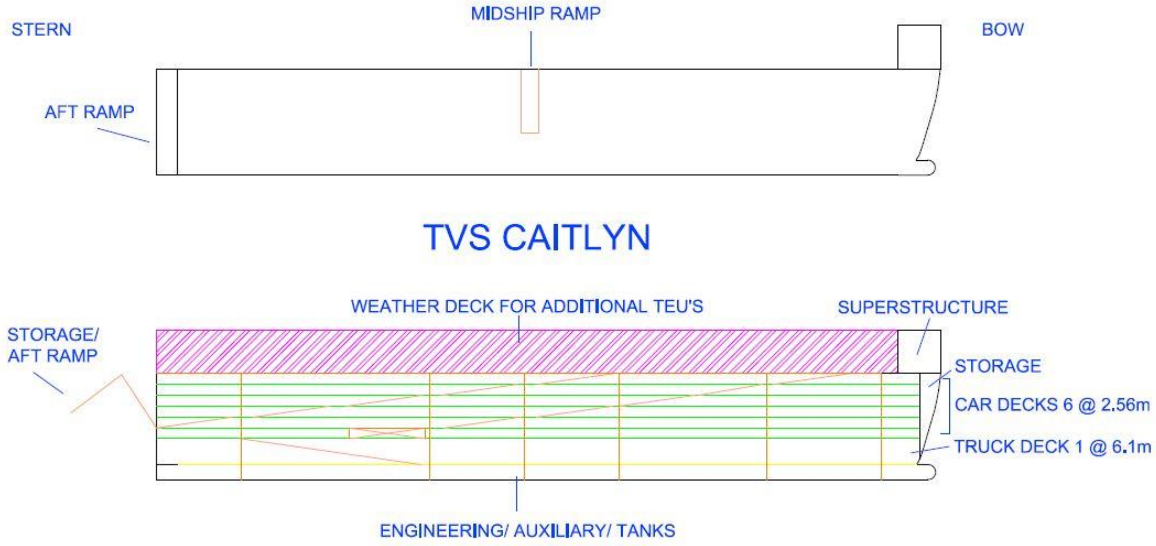

Figure 8: General Solution to the Design

3. Preliminary Designs

3.1. Hull Lines (Written by Lauryn Emmitte)

The hull lines of *Caitlyn* were based off of the general shape of a Ro-Ro, particularly the *Corona Seaways*, as well as creativity. The process began by drawing the Half Breadth Plan because it was easier to visualize the ship by waterlines as opposed to stations. Then, the Body Plan and the Sheer Plan could be constructed. After much drawing trial and error, TVS finally came to a solution that resulted in an ideal ship shape. Figures 9, 10, and 11 are the plan views that show this solution.

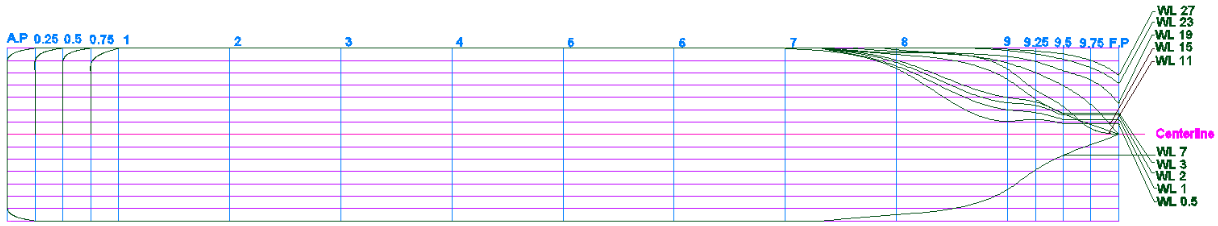

Figure 9: Half Breadth Plan

In the Half Breadth Plan, each water line can be seen in green. The blue represents each station from the aft perpendicular to the fore perpendicular. The centerline is indicated in magenta and the buttocks lines are purple.

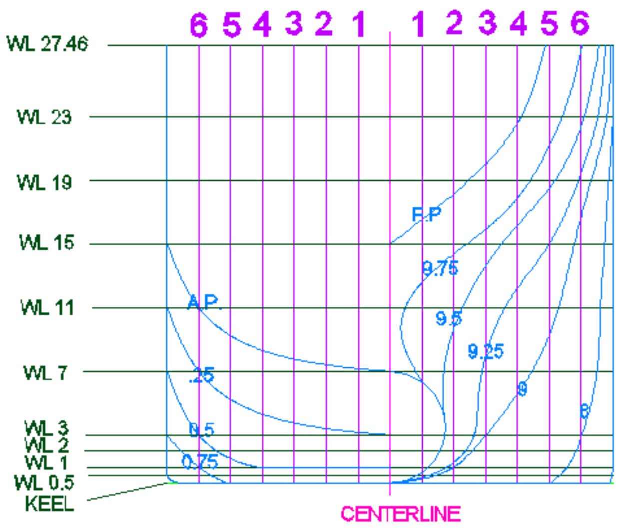

Figure 10: Body Plan

The Body Plan of the vessel is given in Figure 10. The colors explained previously represent each waterline, buttock line, station number, and buttock line respectively. This is the plan that was primarily used to extract points for the construction of the table of offsets.

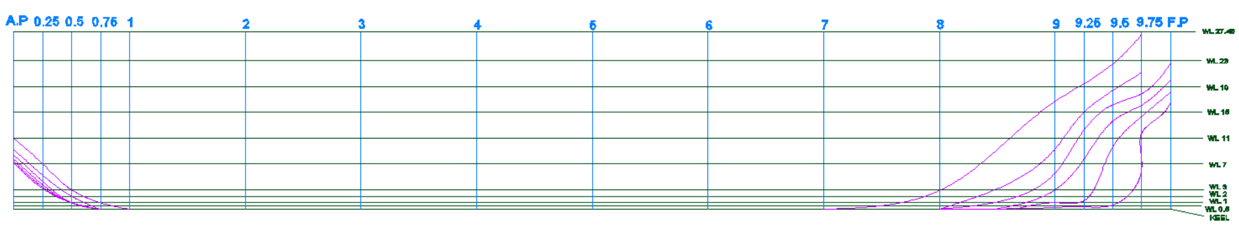

Figure 11: Sheer Plan

Finally, the Sheer Plan was drawn. Like the other two drawings, the colors that represent each element were used consistently.

3.2. Table of Offsets (Written by Lauryn Emmitte)

The process of obtaining the table of offsets, as seen in Table 2, was completed by extracting points from the Body Plan. By the use of AutoCAD, the distance from the keel to the respective waterline could be drawn. Then, a perpendicular line was drawn until it reached the fore perpendicular station. The point at which this line touches the station is the point that was recorded. Then, the line is extended until it reaches station 9.75, 9.5, and so on, with those points recorded respectively. This procedure was repeated for every water line at every station both fore and aft. By completing this, a complete table of offsets was produced.

Table 2: Table of Offsets

TVS - RORO 1 - TABLE OF OFFSETS FINAL												
			Waterline Numbers									
Length Along Ship	Station Number	Keel	0.5	1	2	3	7	11	15	19	23	27
0	A.P.	0	0	0	0	0	0	12	12	12	12	12
4.5	0.25	0	0	0	0	0	12	14	14	14	14	14
9	0.5	0	0	0	10.868	12	14	14	14	14	14	14
13.5	0.75	0	11.257	12	13.09	14	14	14	14	14	14	14
18	1	0	13.936	14	14	14	14	14	14	14	14	14
36	2	0	13.936	14	14	14	14	14	14	14	14	14
54	3	0	13.936	14	14	14	14	14	14	14	14	14
72	4	0	13.936	14	14	14	14	14	14	14	14	14
90	5	0	13.936	14	14	14	14	14	14	14	14	14
108	6	0	13.936	14	14	14	14	14	14	14	14	14
126	7	0	13.936	14	14	14	14	14	14	14	14	14
144	8	0	10.697	11.11	11.664	12.046	13	13.213	13.475	13.734	14	14
162	9	0	2.15	4	5.15	6	8.91	10.581	11.574	12.646	13.623	13.848
166.5	9.25	0	2.461	3.563	4.71	5.278	5.777	7.217	10	11.842	13.046	13.51
171	9.5	0	1.7676	2.4142	3.127	3.4288	3.3811	4.545	7.915	10.363	12.196	13.061
175.5	9.75	0	1.7676	2.4142	3.127	3.4288	1.6231	0.9524	4.8301	8.8078	10.829	12
180	F.P.	0	1.7676	2.4142	3.127	3.4288	0	0	0	4.962	8.246	9.638

As an example of point extraction, waterline 7 was drawn 7 meters up because TVS decided to make the waterlines equivalent to the number of meters above the keel. The perpendicular distance to the fore perpendicular was 0 because this waterline does not touch this station. However, it does reach 9.75, 9.5, etc., as seen in Table 2.

4. Hydrostatics

4.1. Variable Definition (Written by Micah Thoms)

Because there are numerous variables associated with this project, a concise list of all important values is given below.

Table 3: Variable Definitions for Hydrostatics

Variable	Units	Definition
K	Location	Keel
Awp	m^2	Area of the horizontal waterplane
∇ (Nabla)	m^3	The Underwater Volume
Am	m^2	Area of the Amidships at Draft
d	m	Draft
B	m	Breadth
L or LOA	m	Length Overall
Lpp	m	Length Between Perpendiculars
		Coefficients
Cb	-	Block **(**∇ /L*B*d)
Cm	-	Amidships (Am/d*B)
Cwp	-	Waterplane (Awp/L*B)
Cp	-	Prismatic (Cb/Cm)
Cvp	-	Vertical Prismatic (∇/d*Awp)
TEU	tonne	Twenty Foot Equivalent Unit for Cargo Containers
$\overline{KG}$	m	Keel to Center of Gravity (Transverse)
$\overline{KB}$	m	Keel to Center of Buoyancy (Transverse)
$\overline{BM}$	m	Center of Buoyancy to Metacentric Height. (Transverse and Longitudinal)
$\overline{\mathbf{GM}}$	m	Center of Gravity to Metacentric Height (Transverse and Longitudinal)
k	m	Radius of Gyration
I	m^4	Second Moment of Area (Transverse and Longitudinal)
g	m/s^2	Gravity
MCTC	ton-m/cm	Moment to Change Trim One Centimeter

4.2. Underwater Volume (∇) and Amidships Area (A_m) Calculation (by Micah Thoms)

The underwater volume of the TVS *Caitlyn* was calculated using the numerical method of Simpson's composite rule. Essentially, a double integral was performed. The first integral calculated the waterplane area at each respective waterline (K - 7 m) on the table of offsets. An example of waterline seven this can be seen in Appendix 1. The results are shown in Table 4.

Table 4: Area of the Waterplanes.

Draft (m)	Awp (m^2)
0.5	3966.658
1	4064.734
2	4215.597
3	4277.548
5	4451.798
7	4496.738

Each respective waterplane area was then inserted into the second Simpson's composite integral. This method resulted in an underwater volume (∇) of 29,444.438 m^3. The spreadsheet used can be seen in Appendix 2.

Table 5: Underwater Volume (∇)

Draft (m)	Nabla (m^3)
1	3321.894
3	11723.451
7	29444.438

To find the underwater volume at any given point, the above points were graphed and a 2^{nd} degree polynomial line of best fit equation was found, having an R value of 1; meaning accuracy was 100%. An approximation could be made with little error. This concept help in the calculations of forthcoming coefficient values. The equation of best fit was rearranged in MAPLE to solve for ∇ and multiplied by 10^5. An example can be seen in Figure 12 Below. The Maple document can be seen in Appendix 4.

$$Draft := 6$$

$$6$$

$$NAB = 2.596872948 - 0.00002118599182\sqrt{1.511469013\ 10^{10} - 4.72010000\ 10^{8}\ Draft}$$

$$NAB = 0.248892439$$

Figure 12: MAPLE (∇) Calculation Example

The area of the amidships vertical plane (Am) was calculated in the same matter as the waterplane areas with Simpson's composite rule of integration. Only one integral set at each waterline was needed, considering that ∇ was calculated with the waterplane areas. The results are shown in Table 6 below and in Appendix 3.

Table 6: Area of the Amidships at Draft.

Draft (m)	Am (m^2)
1	23.248
3	79.248
7	191.248

4.3. Curves of Form (by Micah Thoms)

The curves of form for TVS *Caitlyn* relates aspects of the ship's hull to geometric shapes.

- The Block Coefficient is the ratio of ∇ to the cubic shape of the hull.

$$(\nabla / L*B*d)$$

- The Vertical Prismatic Coefficient is the ratio of ∇ to a cylinder created by the Awp multiplied by draft.

$$(\nabla / d*Awp)$$

- The Area of the Waterplane Coefficient is the ratio of the Awp to the Rectangular area created by the Breadth and the length of the waterplane.

$$(Awp/L*B)$$

- The Amidships Coefficient is the ratio of the Am to the vertical rectangular plane area created by the breadth and draft.

$$(Am/d*B)$$

- The Prismatic Coefficient is the ratio of Block Coefficient to the Amidships Coefficient. It also relates ∇ to a cylinder shape of the maximum area of the vessel to the length.

$$(Cb/Cm)$$

Each of the above respective equations, combined with the Simpson and MAPLE values discussed in the previous section, yielded the results for different drafts in Table 7 below. At designed draft, the coefficient values are in the 0.83-0.98 range. This defines the vessel as relatively block shaped. The result is not unusual for Ro-Ro vessels.

Table 7: Block Coefficients

Draft (m)	Cb	Cvp	Cwp	Cm	Cp
1	0.66	0.82	0.81	0.83	0.79
3	0.78	0.91	0.85	0.94	0.82
7	0.83	0.94	0.89	0.98	0.86

All of the results from Table 7 were plotted to create a Curves of Form graph. Figure 13 below displays the curves of form for TVS *Caitlyn*. Given a visual representation of the data, it is easy to see how the coefficients increase as the draft increases. Essentially, the ship becomes "boxier" as distance from the keel increases. This graph is also where the Simpson and MAPLE results for ∇ were plotted on a secondary axis to find the line of best fit. These plots were integral in finding the hydrostatic values.

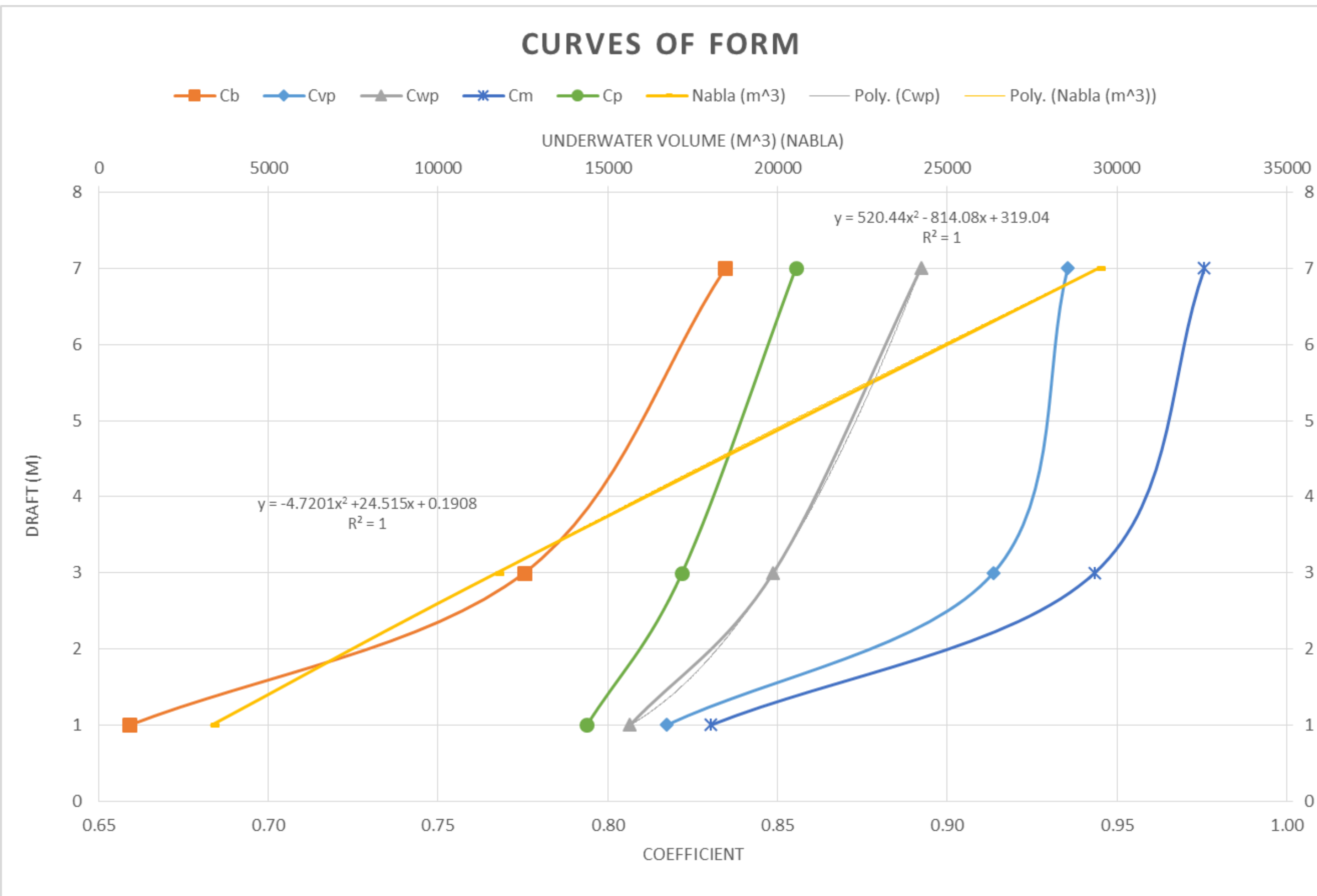

Figure 13: Curves of Form

4.4. Calculating Keel to Center of Gravity Distance ($\overline{KG}$) (Written by Micah Thoms)

To accurately approximate $\overline{\mathrm{KG}}$, The centroids of the cargo, ballast, fuel, engines and ship structure needed to be calculated.

To find the centroid of the cargo, each deck height, cargo type and the average weight of cargo needed to be considered. For example, the average car is 1.7 tonne and the average TEU is 12-14 tonnes. The sum of the moments created by the cargo and deck height divided by the sum of the weight of the cargo was used. Working with the cargo stowage arrangement, the ideal loading was found and displayed in Table 8 below. The cargo weight is 17,237.187 tonne at 14.811 meters above the keel.

Table 8: Cargo Loading and Centroid Location

Finding Weight and Centroid of the Cargo								
Deck Number	Deck Height (m)	Cars on each deck	TEUs on each deck	Weight of cars (tonne)	Weight of TEUs (tonne)	Sum of Moments (tonne-m)	Sum of Forces (tonne)	Centrod From Keel (m) Centroid (m)
Weather	27.5	0	391	0	4692	128842.320	17237.187	14.811
1	24.6	308	0	524.6472	0	12923.267		
2	21.8	411	0	700.0974	0	15265.344		
3	19.0	404	0	688.1736	0	13059.402		
4	16.1	388	0	660.9192	0	10673.316		
5	13.3	191	110	325.3494	1540	24849.252		
6	10.5	0	213	0	2982	31292.512		
Truck	3.6	0	366	0	5124	18395.160		
TOTAL		1702	1080			255300.573		

The total weight and centroid of the ship structure was found using Sesam GeniE. All of the structural information was plugged into the program, along with all of the specific material information. The resulting weight was 3,505 tonne at a centroid of 14.800 meters above the keel.

The total weight of two MAN B&W engines is 270 tonne at an estimated 3 meters above the keel.

The total weight of the seawater ballast is calculated by taking the volume of the ballast tanks and multiplying by the density of seawater to give tonne.

$$(Length * Width * Height)_{tank} * \rho_{seawater} = tonne\ of\ Ballast\ Sewater$$

⇨ $(117\ m * 28\ m\ * 1.4\ m)_{tank} * 1.025 \frac{tonne}{m^3} = 4707\ tonne$ at a centroid of 0.7 meter

The total weight of the loaded fuel tank (Diesel #2) is calculated by taking the volume of the fuel tank and multiplying by the density of fuel to give tonne.

$$(Length * Width * Height)_{tank} * \rho_{fuel} = tonne\ of\ fuel$$

⇨ $(58.5\ m * 25.5\ m\ * 3\ m)_{tank} * 0.832 \frac{tonne}{m^3} = 3723.4\ tonne$ at a centroid of 1.5 meter

Having all the weights and centroid locations allow for the Full Load $\overline{KG}$ to be calculated. Removing the Cargo weight and centroid allow the Ballast condition to be calculated. Removing the seawater ballast and fuel allow the Light Ship condition to be calculated. This process is demonstrated in Table 9. The results for $\overline{KG}$ are given in Table 10.

Table 9: Total Weights and Moments

Finding Total Weights and Moments		
Weight (tonne)	Centroid From Keel (m)	Moment (tonne-m)
17237.187	14.811	255300.573
3505.000	14.800	51874.000
4707.000	0.700	3294.900
3723.400	1.500	5585.100
270.000	3.000	810.000
Total Weight (Full Load)		Total Moment
29442.587		316864.573
Total Weight (Ballast)		Total Moment
12205.400		61564.000
Total Weight (Light Ship)		Total Moment
3775.000		52684.000

Table 10: Final KG Values

Final KG			
-	Full Load	Ballast	Lightship
Draft (m)	7.000	3.113	1.110
NABLA (m^3)	29442.587	12205.400	3775.000
KG (m)	10.762	5.044	13.956

4.5. Light Ship, Ballast, Half- and Full-Load Conditions (Written by Micah Thoms and William Foy)

After compiling each $\overline{\mathrm{KG}}$ value for the three vessel loading conditions, hydrostatic analysis was performed. The next value to calculate was the keel to center of buoyancy ($\overline{\mathrm{KB}}$). This process involved using Equation 3-10b from the textbook.

$$\overline{\mathrm{KB}} = d\left(\frac{Cwp}{Cwp+Cb}\right)$$

In the curves of form, a line of best fit equation was calculated for Cwp and Cb. In MAPLE the 2nd order polynomial equation was rearranged to solve for Cwp and Cwp at any given draft. This data was checked by ensuring the results matched up with the Simpson values discussed in the Curves of Form section. Plugging in the now known coefficients into Equation 3-10b resulted in $\overline{\mathrm{KB}}$ values for the drafts found in the $\overline{\mathrm{KG}}$ section. Table 11 below shows this data. $\overline{\mathrm{KB}}$ Longitudinal and $\overline{\mathrm{KB}}$ transverse are defined to be the same value.

Table 11: KB Results

Results for KB				
Nabla (m^3)	Draft (m)	Cwp	Cb	KB
29444.438	7.000	0.892	0.835	3.617
24889.244	6.000	0.883	0.823	3.106
20420.239	5.000	0.873	0.810	2.593
16033.189	4.000	0.862	0.795	2.080
11723.745	3.000	0.849	0.775	1.568
7487.926	2.000	0.832	0.743	1.057
3322.085	1.000	0.807	0.659	0.550

$\overline{\mathrm{BM}}$ Transvers and Longitudinal values were calculated when the Awp for each draft was calculated using Simpson's composite rule. This was accomplished by taking the second moment of area with respect to the X and Y axis. An example for waterplane seven can be seen in Appendix 1. The values calculated are displayed in Table 12.

Table 12: BM Results

Results for BM			
Nabla (m^3)	Draft (m)	BM	BM (long)
29444.438	7.000	9.313	1389.008
24889.244	6.000		
20420.239	5.000	13.181	2000.725
16033.189	4.000		
11723.745	3.000	22.055	3381.480
7487.926	2.000	33.103	5147.281
3322.085	1.000	66.550	11045.298

The hydrostatic values were all compiled and $\overline{\mathrm{GM}}$ was calculated using the $\overline{\mathrm{GM}}$ equation. The same equation is used for transverse and longitudinal with only $\overline{\mathrm{BM}}$ and $\overline{\mathrm{GM}}$ having a differing value.

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$$

The results of the hydrodynamic analysis is displayed in Table 13 below.

Table 13: Final Hydrostatics

Hyrdostatics			
-	Full Load	Ballast	Light Ship
Draft (m)	7.000	3.111	1.110
Nabla (m^3)	29444.438	12207.000	3775.000
KB (m)	3.617	1.626	0.600
BM (m)	9.313	23.000	60.000
KG (m)	10.762	5.044	13.956
GM (m)	2.168	19.582	46.644
KB L (m)	3.617	1.626	0.600
BM L (m)	1389.008	3381.430	9958.600
KG L (m)	10.762	5.044	13.956
GM L (m)	1381.863	3378.012	9945.244
Radius of (m) Gyration	7.809	7.731	7.694
Rolling Period (s)	10.634	3.503	2.259
MCTC (ton-m/cm)	2199.360	2134.512	2077.814

With all positive $\overline{\mathrm{GM}}$ values, the vessel is stable under all loading conditions. The radius of gyration was calculated using the equation:

$$k = \sqrt{\frac{I_T}{Awp}}$$

The rolling period of the vessel was calculated using the rolling period calculation.

$$Rolling\ period = \frac{2\pi * k}{\sqrt{\overline{\mathrm{GM}} * g}}$$

The rolling period is in the cruise ship rolling period range for Full load. It decreases for Ballast condition, and at light ship the rolling period is rather swift due to the fact there is no cargo, ballast, crew, liquids or loads of any kind. The Ship structure is the only factor. This could be mitigated by changing some of the ship structure in later design iterations.

The Moment to Change Trim One Centimeter (MCTC) is given by the equation:

$$MCTC = \frac{\nabla * \overline{\mathrm{GM}}}{100 * LOA}$$

The results are shown in the above Table 13.

4.6. Damage Stability (Written by Zachary Gonzales)

A vessel is exposed to a hostile environment while at sea. The most serious concern is ultimately the loss of reserve buoyancy, which may result in sinking of the ship. An important contributive factor to this loss of buoyancy is the loss of stability through uncontrolled flooding, which may or may not result in the vessel capsizing before sinking.

The method for calculating TVS *Caitlyn's* stability in the damaged condition is called the "Constant Buoyancy Method". This method assumes that $\overline{KG}$ (center of gravity) of the vessel is constant throughout each damaged condition, although the LCF (longitudinal center of flotation) and other stability characteristics will vary with each. This assumption follows Archimedes' principle in that the upward buoyant force exerted on a body immersed in a fluid is equal to the weight of the fluid that the body displaces.

There were three different damaged conditions considered for the design. Flooding fore of the collision bulkhead, slightly aft of amidships, and aft of the engine bulkhead. All damage conditions were calculating assuming a water depth rising into the vessel of seven meters. The seven-meter flooding height translates to flooding of the entire lower heavy equipment deck and accounts for one meter of flood water above it. Although this deck is watertight, these conditions assume the watertight properties are compromised. The seven-meter flooding was chosen because a practical damaged condition was desired, furthermore, a damage condition that still allowed passage through the Panama Canal was assumed to be ideal. It should be noted that each flooded compartment was assumed to be symmetric with respect to the centerline, so that no list moment was created.

Visual representations of the flooded areas on a barge (for simplicity) with TVS *Caitlyn's* LOA and breadth are provided below in Figure 14.

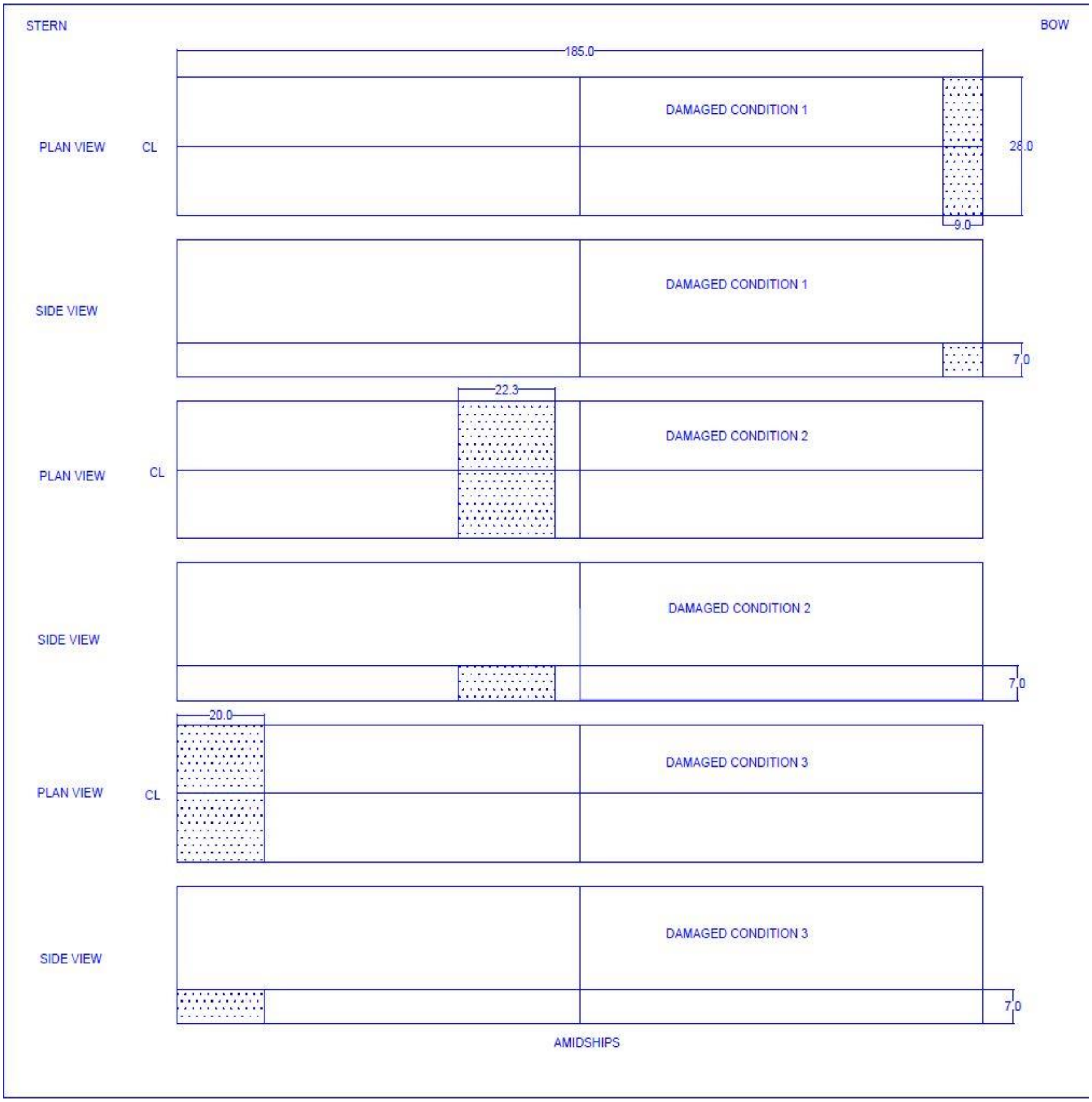

Figure 14: Damage Stability Drawing

In order to perform damage stability calculations using the Constant Buoyancy Method, several parameters regarding each flooded condition were established. First, the volume of each flooded compartment was calculated using Simpson's 1st Rule of Approximation from the cross sectional area of each bulkhead and considering the length of each compartment along the ship. Also, the permeability coefficient μ for each condition was assumed to be 0.95, which is a typical conservative assumption for cargo areas on a Ro-Ro vessel.

Listed below are some of the governing equations and their explanations for the Constant Buoyancy Method of damaged stability.

Equation 1: Finds the angle of trim due to the moment created by the distance from the LCF to the flooded compartment's centroid. Where ρ is the density of water, μ is the permeability coefficient, v_{co} is the volume of the flooded compartment, x_c is the distance from the LCF to the centroid of the flooded compartment, x_f is the original LCF, Δ is the ship's displacement, and $\overline{GM}_L$ is the longitudinal metacentric height for the vessel. Note that this angle is calculated in radians. In order to correctly calculate the trim caused by the damaged compartment, the angle must be converted to degrees. Trigonometry must then be employed to calculate the new draft.

$$\theta_{rad} = \rho(\mu v_{co}(x_c - x_f)/\Delta\overline{GM}_L$$

Equation 2: Calculates the change in draft due to the added tonnage of the water taken aboard. Where A_{wp} is the area of the waterplane that the flood water reaches, μ_s is the surface permeability coefficient, and a is the area of the flooded compartment. Also known as parallel sinkage.

$$\delta d = \mu v_{co}/(A_{wp} - \mu_s a)$$

Equation 3: This equation states that the longitudinal metacentric height after damage is nearly equal to the longitudinal metacentric radius after damage. This is useful because if $\overline{BM}_L{}'$ can be calculated, it can be used to substitute into Equation 1 for $\overline{GM}_L$ to find the trim angle after damage.

$$\overline{GM}_L{}' \approx \overline{BM}_L{}'$$

Equation 4: Finds the longitudinal metacentric radius after damage.

$$\overline{BM}_L' = I_L'/\nabla$$

Equation 5: In order to solve for the metacentric radius after damage mentioned above, I_L' must be solved for using the equation below. Where I_L is the original moment of inertia about the ship's centerline, x_F' is the new location of the LCF after damage, and $i_L$is the moment of inertia about the compartment's longitudinal axis.

$$I_L' = I_L + A_{wp}(x_F - x_F')^2 - \mu(i_L + a(x_a - x_F{}')^2$$

Equation 6: Finally, the last equation will calculate the new draft of the bow and stern of the vessel (depending on where the flooded compartment is compared to the LCF).

$$d' = d_0 + d_{parallel\ sinkage} \pm d_{due\ to\ trim}$$

The results of the aforementioned calculations are given in Table 14 below.

Table 14: Flooding Conditions

	Flooding Condition		
	Fore of the Collision Bulkhead	Aft of Amidships	Aft of the Engine Bulkhead
Design Draft [m]	7	7	7
Volume of water taken aboard [m^3]	1481.76	4370	3920
Parallel Sinkage [m]	0.3285	1.13	0.996
Draft change due to trim [deg]	0.003	0.0013	0.03
Damaged Stern Draft [m]	7.32	8.13	8.026
Damaged Bow Draft [m]	7.33	8.12	7.966

It should be noted that the draft to traverse the Panama Canal is never exceeded in these damaged conditions, but the specified draft by Rotto Nordic Lines of 7.2 m is exceeded in the aft of amidships and aft of the engine bulkhead flooding conditions. This is due to the fact that the volume of water taken on is much larger with respect to the first flooding condition fore of the collision bulkhead.

5. Arrangements

5.1. Cargo Stowage (Written by Lauryn Emmitte)

ECG's *Operations Quality Manual for Commercial Vehicles* has a chapter regarding cargo spacing within Ro-Ro vessels. According to this document, Volvo approves of this manual for vehicle handling. For this reason, Transglobal Vehicular Solutions decided to use this document as a guide to storing cargo.

For starters, Volvo's largest car dimensions were used in the storage analysis. This was chosen because even if the owner decided to choose smaller Volvo cars to transport, it would be guaranteed that they would fit. The longest vehicle is 4.84 meters and the widest is 1.89 meters. Therefore, these were the dimensions chosen to represent a car on each deck.

The document states that each vehicle must have 10 centimeters between them, mirror to mirror. There also must be 30 centimeters of space fore and aft between vehicles, and 30 centimeters between the bumper and the ship's superstructure. Additionally, 15 centimeters of space is required between the vehicle and the superstructure. Because the ship's side structure has a web frame that sticks out a total of 1 meter, there must be at least 1.15 meters of space between the car and side structure. By placing the cars in AutoCAD, it can be seen that this requirement is met by having a total of 1.225 meters of space. A schematic of this is given in Figure 15.

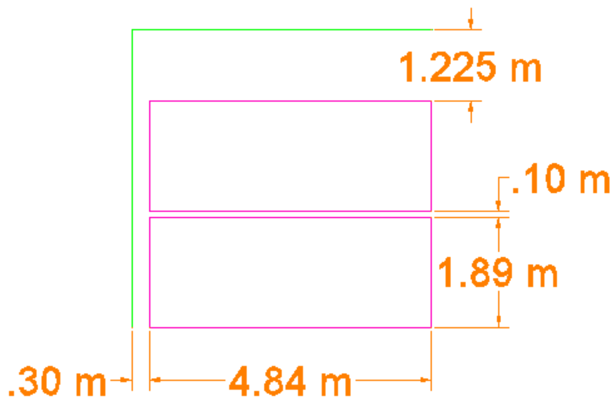

Figure 15: Cargo Stowage

As seen in Figure 16, the cars are arranged as required. The TEUs are packed even tighter together with a spacing of 25 centimeters between. They also meet the above requirements of side structure spacing.

5.2. General Arrangement (Written by Lauryn Emmitte)

The ship was designed to have 8 cargo decks, including the weather deck. Knowing the height of each, and therefore its distance above the keel, was essential to creating the shell of each deck space. A separate table of offsets was extracted from the Body Plan in order to draw them. Before vehicles were placed on the individual shells, the bulkheads had to be implemented. They were positioned respective to their calculated location (as seen in Chapter 6) and can be seen in orange. The general layout of the solution is given in Figure 16.

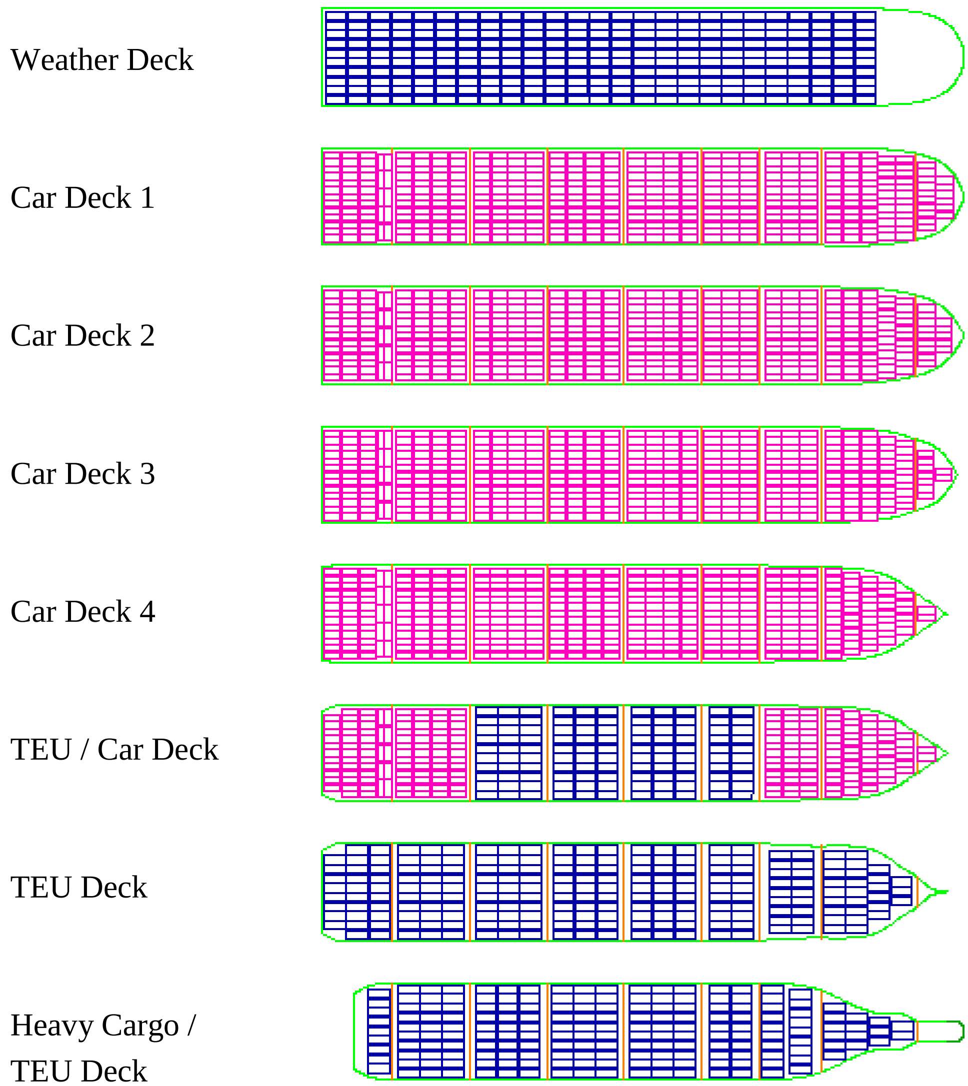

Figure 16: General Arrangement

Magenta represents the cars and blue represents TEUs in the figure above. The final car count totaled to be 1,808. This includes 414 on Car Deck 1, 411 on Car Deck 2, 404 on Car Deck 3, 388 on Car Deck 4, and 191 on the TEU / Car Deck. The total number of TUEs came out to be 1,189. There are 500 on the weather deck that are double stacked, 110 single stacked on the TEU / Car deck, 213 single stacked on the TEU Deck, and 366 double stacked on the Heavy Cargo / TEU Deck. This is the absolute maximum capacity that the ship can hold.

5.3. Manning and Accommodation (Written by Chris Williams)

The crew for the vessel was determined based upon the regulations given by SOLAS. The regulations stated that for a vehicle carrier carrying over 12 passengers the vessel is to be considered a passenger vessel. Any number of passengers exceeding this value requires the vessel to not carry cargo below the designed water line. This would affect the TVS *Caitlyn* because the lower truck deck is designed to carry cargo below the water line. A team of 8 crew members will provide a sufficient amount to man the vessel. This allows for several engineers as well as crew to pilot the vessel plus 4 guests as stated in the requirements.

For the accommodations, the crew will have three levels, each 500 square meters, on the super structure. The first level will consist of the galley, workout room and reading room where the crew can work out, eat and take breaks. The second level will be where the bunks and two lounge rooms will be. The lounges will consist of oversized chairs and large televisions to allow the crew to relax and watch TV. The top level will be the bridge, state rooms for the captain, and a large meeting room. The bridge will have bridge wings on either side to aid in navigation once in port. The bridge is designed to control the vessel from the bow and stern ends giving a full view of the vessel. The meeting room will be designed for teleconferences to allow the captain and officers to talk with companies while the vessel is underway.

6. Structural Hull Design

The society chosen to class the vessel was the American Bureau of Shipping. It was picked because the information was readily available. The ABS documents regarding roro specifications were used in order to determine structural details of the ship. This was within the *Steel Vessels 2015* document. It was primarily *Part 3: Hull Construction and Equipment* as well as *Part 5C Specific Vessel Types (Chapters 7-12).* The procedures for obtaining the required structural elements can be seen below.

6.1. Shell Plating (Written by Christopher Williams)

- Side shell plating
  - t= $\frac{sk\sqrt{qh}}{254} + 2.5\ mm$
  - s= 2.08L + 438 + 822.8 mm (where L is length of vessel)
  - k =1 amid ship and 1.33 at ends
  - q= 235/y (y is yield strength of steel = 250MPa)
  - h= 0.1L (where L is length of the vessel)
  - Thickness amidships = 16.01 mm amidships
  - Thickness fore and aft = 20.47 mm
- Sheer strake
  - b= 5L+800 mm
  - b = 1725mm
- Bottom shell plating
  - t = s(L+45.73)/(25L+6082) mm
  - s= 2.08L + 438 + 822.8 mm
  - L is length of the vessel
  - Thickness = 17.73 mm
- Keel plate
  - t = 1.5+ $t_{\text{bottom shell}}$

- Thickness = 19.23 mm

- Shell plating at ends
  - $t = 0.0035(L+29) + 0.009s$ mm
  - L is the length of the vessel
  - $s = 2.08L + 438 + 822.8$ mm
  - Thickness = 14.9
- Immersed bow plating
  - $t = 0.05(L+20) + 0.009s$ mm
  - Thickness = 17.66 mm

6.2. Deck Plating (Written by Christopher Williams)

- Strength Deck plating
  - $T = 0.01(S_d) + 0.9$ mm
  - S_d is spacing of stiffeners
  - Thickness = 7.44mm
- Car decks
  - $t = k\mathbf{K}n\sqrt{W}$
  - k= 8.05 (given by ABS)
  - $\mathbf{K} = 21.99 + 0.316(a/s)^2 - 5.328(a/s) + 2.6(a/s)(b/s) - 0.895(b/s)^5 - 7.624(b/s)]*10^2$
    - a is the parallel wheel imprint dimension
    - b is the perpendicular wheel imprint dimension
    - s is the longitudinal deck spacing
  - W is the weight of the vehicle
  - Thickness is 4.2 mm
- Inner bottom plating
  - $t = 0.037L + 0.009s - c$ mm
  - L is the length of the vessel
  - s is the spacing of the supports
  - c is 1.5 given by ABS
  - Thickness = 12.8 mm

6.3. Keel (Written by Christopher Williams)

- Amidships
  - $t = 0.056L + 5.5$ mm
  - Thickness = 15.86 mm
- Fore and aft of the vessel
  - t = .85* thickness amidships
  - Thickness = 13.5 mm

6.4. Longitudinal Stiffeners (Written by Christopher Williams)

- $SM = M_t/F_p$ cm^2-m for amidships
  - M_t is the total bending moment
  - F_p is the nominal permissible bending stress

- $SM = 1135\ cm^2 - m$

- Minimum Section modulus for side girders
  - $SM = C_1C_2L^2B\ (C_b+0.7)\ cm^2\text{-}m$
  - $C_1 = 10.75 - (\frac{300-L}{100})^{1.5}$
  - $C_2 = 0.01$ (given by ABS)
  - B is breath of vessel
  - C_b is the block coefficient of the vessel
  - $SM = 759\ cm^2\text{-}m$
  - Thickness is found by
    - $t = 0.036L + 4.7 + c$
    - L is the length of the vessel
    - C is given as 1.5 by ABS
    - Thickness = 12.86 mm

6.5. Transverse Frames (Written by Christopher Williams)

- Transverse frame below lowest deck
  - $SM = sl^2\ (h+(bh_1/30))(7+45/l^3)\ cm^3$
  - s is frame spacing
  - h is .4*l
  - l is height from the bottom to the next deck
  - b is the horizontal distance, in meters, from the outside of the frame to the row of deck supports
  - h_1 = vertical distance, in meters, from the deck at the top of the web frame to the bulkhead or freeboard deck plus the height of all cargo tween deck spaces.
  - SM = 530 cm^3
    - Thickness of 7.86 mm
- Hold web frames amidships and aft
  - $SM = 4.74*csl^2\ (h+(bh_1/45k)\ cm^3$
  - c= 1.5 (ABS)
  - k= 1 when longitudinally framed
  - SM of truck deck = 2,184 cm^3
    - Thickness of 11.13 mm
  - SM of car decks = 174.74 cm^3
    - 1Thickness of 6.7 mm
- Hold webs forward and aft
  - To be same as web frames amidships
- Side stringers
  - $SM = 4.74*chsl^2$
  - s is the sum of the half lengths in meters of the frame supported
  - l is the span in meters between web frames or between web frame and bulkhead. Where brackets are fitted.
  - SM of 482.5 cm^3
    - Thickness of 10 mm

6.6. Bulkheads (Written by Christopher Williams)

- Bulkheads
  - t = sk$\frac{\sqrt{qh}}{L} + 1.5\ mm$
  - s is the frame spacing
  - k = (3.075*$\sqrt{\alpha}) - 2.077)/(\alpha + .272)$
  - α is the long edge over the short edge of the vessel
  - q = 235/ Ψ
  - Ψ is the yield strength of steel
  - Thickness is 14.2 mm

7. Final CAD Drawings

7.1. Mid-ship Section Drawing with Scantling (Written by Christopher Williams)

The amidships section of the ship was designed by following the ABS classification rules governing minimum thicknesses and section modulus of steel. The amidships shows the double bottom, decks, side web, shell and the stiffeners for each section. Because the ABS standards produce minimum values, the decks were designed thicker in order to help add weight to the vessel and provide more strength. The deck stiffeners were also designed thicker than ABS regulations to help add weight and strength to the vessel as well.

In designing the stiffeners, the longitudinal L-beams are welded to the bottom of the deck. The transverse T-beams are welded to the deck as well but are cut to fit over each L-beam. The hold web was designed to provide stiffness for the side shell of the ship. These stiffeners are placed 2.5 meters apart and run transversely through the ship. The keel is welded to the top and bottom of the double bottom and runs longitudinally through the whole vessel. The side girders are also welded to the top and bottom of the double bottom and run longitudinally the whole length of the vessel. A schematic of this can be seen in Figure 17.

Spaced throughout the length of each side girder are manholes. The manholes will allow for a person to move through sections to make repairs if repairs were ever needed. In between the side girders are T-beam stiffeners, which will provide more strength to the double bottom. Under the keel is the keel plate, this is part of the shell plating and is placed longitudinally down the bottom of the vessel to provide strength. In Table 15 are the members in the midship section and the thicknesses of each member. The final member in the midship section is the ventilation system. This system will move enough air to exchange the air inside the vessel 10 times every hour in port. While underway, the ventilation system will be running at half power because it will only need to be exchange the air 5 times every hour.

Table 15. Amidships section steel members and the respective thicknesses

Steel Member	Thickness (mm)
Side Shell	7
Side Girder	13
Hold Web	13
T-Beam (Decks)	13
T-Beam (Double Bottom)	13
Outer Bottom	18
Inner Bottom	13
L-Beam	13
Keel	16
Keel Plate	19
Decks	7.4

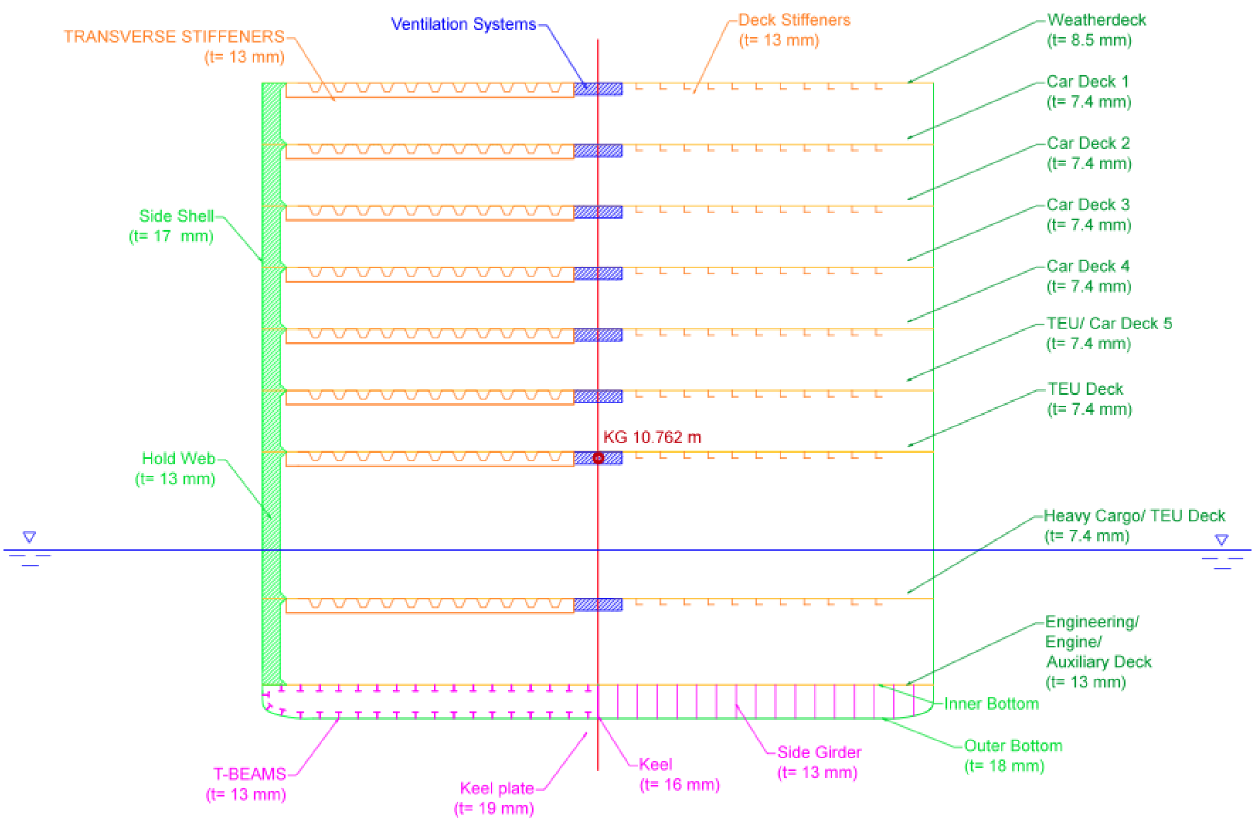

Figure 17: Midship Section Drawing

7.2. GeniE Drawing and HydroD Analysis (Written by William Foy)

In order to determine accurate values for the vessel’s weight, stability, and various other properties, certain modules of a program called Sesam were utilized; namely GeniE and HydroD.

GeniE's main focus was the visualization and construction of the vessel itself, while HydroD conducted dynamic analysis of the ship's motion through water, applying wind and water loads to measure the aforementioned variables. The use of both modules was a lengthy process, requiring many iterations and numerous adjustments in order to obtain the desired results.

To facilitate the learning of these programs, a tutorial was provided by the instructor, which proved invaluable in the design process. This guide began with an introduction to GeniE, and concluded by explaining how to export the newly created ship into HydroD.

Like other design software, GeniE accepts a command called "polyline", which allows for the insertion of multiple points on a single line, greatly simplifying program input. Using the table of offsets, three-dimensional lines were created and written into GeniE, forming the basis for TVS *Caitlyn*'s Hull form, as shown in Figure 18.

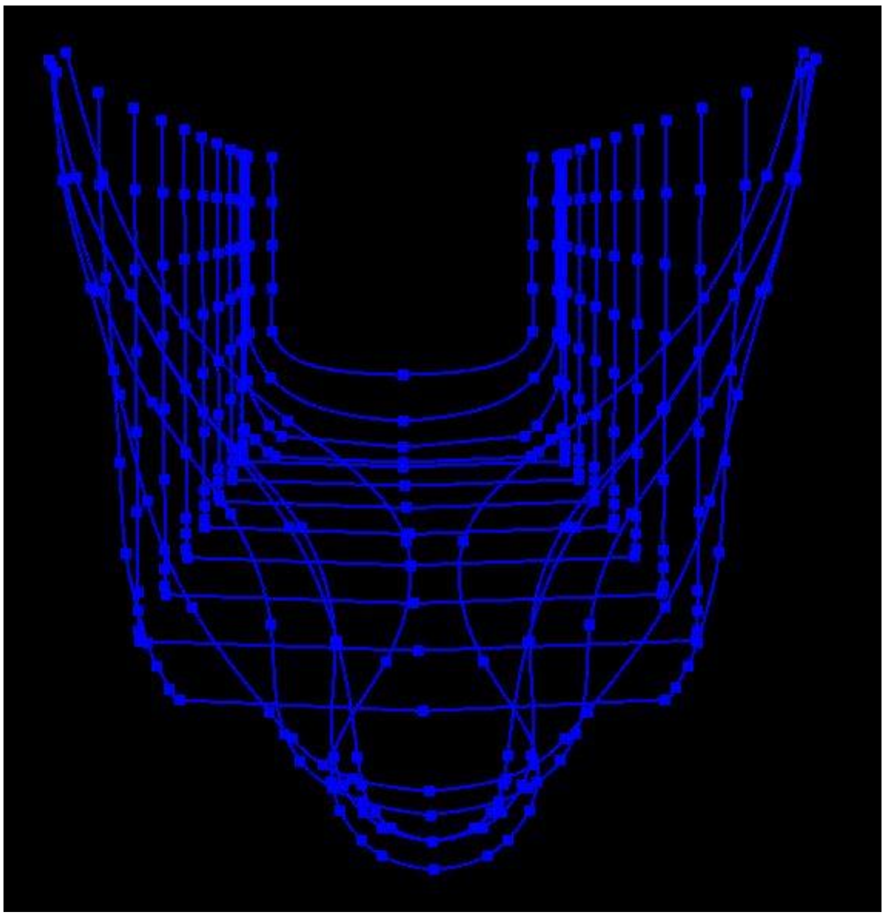

Figure 18: TVS *Caitlyn*'s completed polylines

The X-value of the coordinate system represents the length along the ship longitudinally, the Y-value corresponds to distance from centerline, and the Z-value relates to the height above Keel. Using built-in GeniE commands, the vessel was given plates, decks, and bulkheads, as well as both transverse and longitudinal stiffeners; a cross-section of which is given in Figure 19.

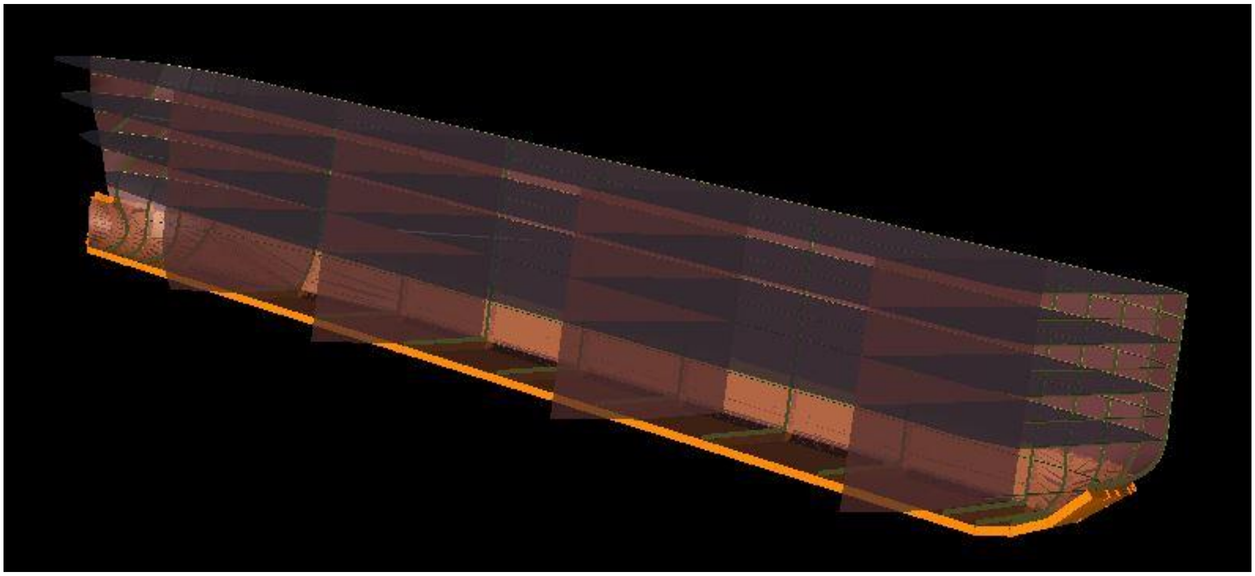

Figure 19: *TVS Caitlyn*'s completed Hull structure

Following the completion of TVS *Caitlyn's* Hull structure, a "load-case" was implemented in order to define the portion of the vessel that would remain underwater during voyage. Because the design draft of the vessel is 7 meters, it follows that the load-case would be defined at this height. The load-case is represented by an orange mesh around the structure, located under the waterplane, which is denoted by a green cutting-plane. A view of the completed vessel is shown in Figure 20 below.

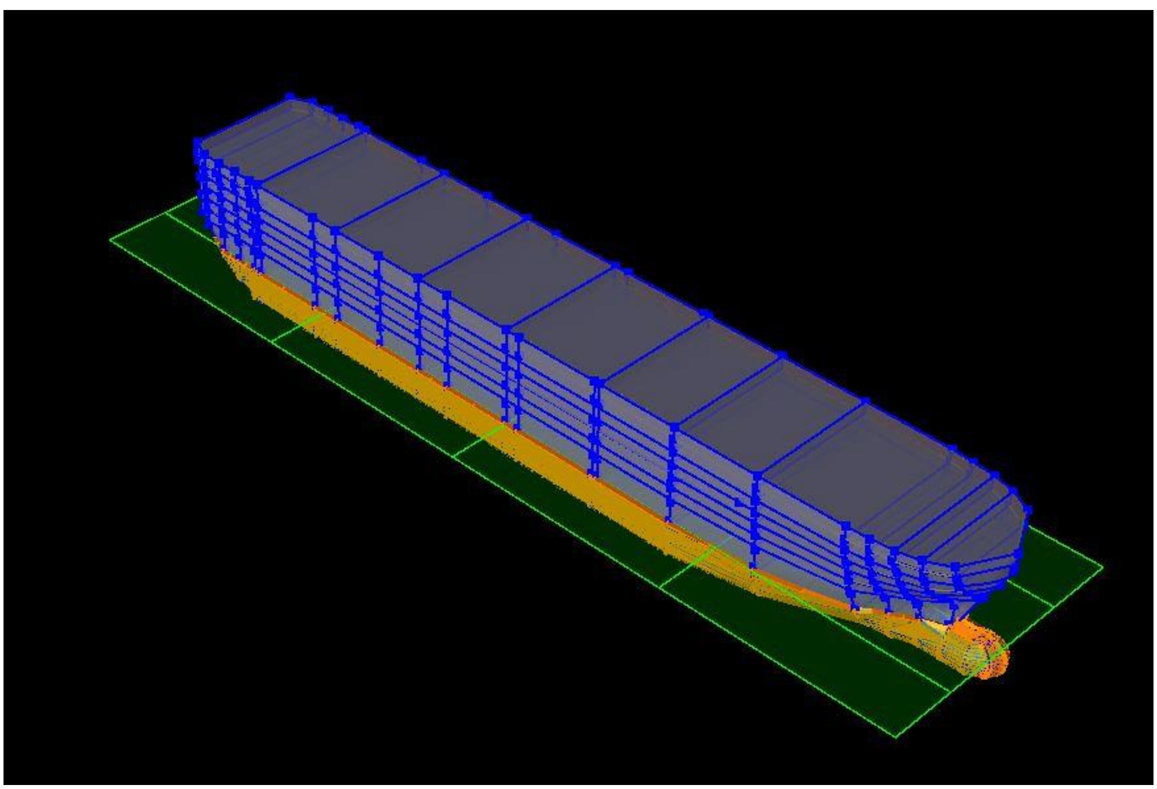

Figure 20: The completed vessel, ready for export into HydroD

Upon finishing the vessel's Hull-lines and structural elements in GeniE, the completed vessel was ready for export into Sesam's second module: HydroD. Following export, HydroD required specific instructions in order to generate a report of the ship's functionality; namely the ship's length, breadth, and design draft. Figure 21 below is a HydroD-rendered image of TVS *Caitlyn* just before analysis.

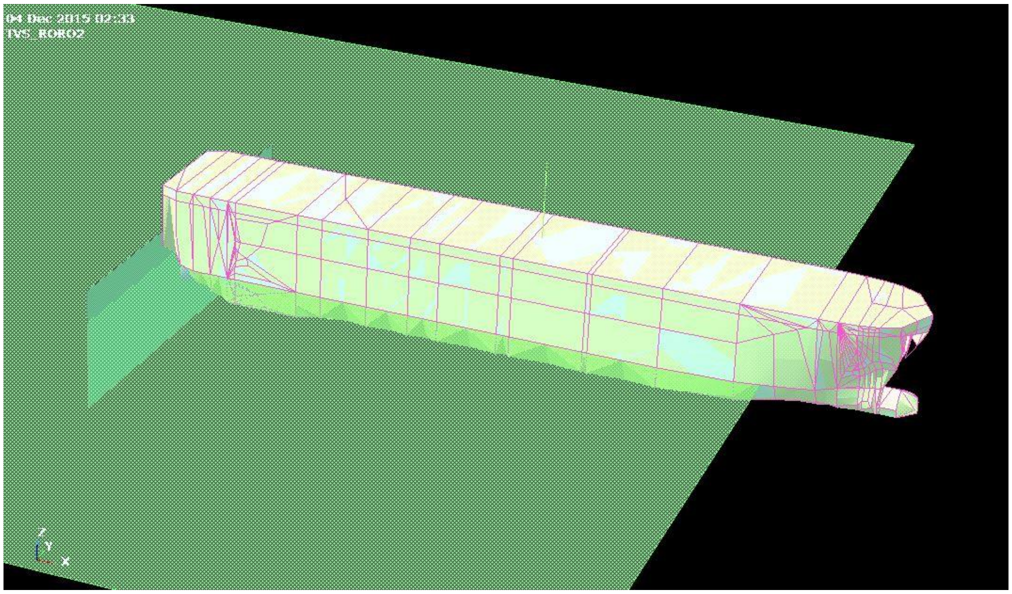

Figure 21: TVS *Caitlyn* just before HydroD analysis

Immediately following analysis of the vessel, HydroD generated a comprehensive report of the ship's stability, mass, and various coefficients. These values proved indispensable in the hydrostatic examination of the vessel, as many could be obtained in no other way. A table of HydroD's stability report is depicted in Table 16 below.

Table 16: HydroD's stability report

	Result Variable	Value (X)	Y	
1	Metacentric Height GM (with FSC)	3.848695826 m		
2	Metacentric Height GM (without FSC)	3.848695826 m		
3	Free surface correction FSC	0 m		
4	Total mass (Damaged) (including compartment contents)	26603882.2 Kg		
5	Total mass (without compartment contents)	26603882.2 Kg		
6	Center of gravity (Damaged)	92.05649771 m	0.04126046921 m	2.934164454 m
7	Center of gravity (without compartment contents)	92.05649771 m	0.04126046921 m	2.934164454 m
8	Center of gravity (with compartment contents in metacenter)	92.05649771 m	0.04126046921 m	2.934164454 m
9	Buoyancy volume	25955.007 m^3		
10	Buoyancy mass	26603882.18 Kg		
11	Center of buoyancy	79.89755648 m	0.02461725473 m	3.741659672 m
12	Center of flotation	82.53835902 m	1.110911759e-006 m	7 m
13	Trim moment	3.890866208e+010 N*m		
14	Panel model block coefficient	0.7120892998		
15	Projected XZ area above waterline	3614.030192 m^2		
16	Center projected XZ area above waterline	90.40850338 m		10.06263771 m
17	Projected XZ area below waterline	1256.979557 m^2		
18	Center projected XZ area below waterline	93.84829491 m		-3.466323808 m
19	Deck immersion heel angle negative side	-89 deg		
20	Deck immersion heel angle positive side	90 deg		

8. Voyage Specific Analysis

8.1. Ship Resistance Analysis (Written by Lauryn Emmitte)

The method of obtaining ship resistance was performed by model testing. In this case, the *Corona Seaways* was used as the model. The first step was obtaining the wetted surface area of *Caitlyn*, which was done by utilizing Mumford's Formula ($S = 1.025*Lpp*[C_B*B+1.7d]$. Then, by using the length scale ($\lambda = 0.989$), the wetted surface of the model could also be determined.

Because the design speed of the model was known, it was pertinent to find the speed of the prototype during this experiment. Froude's number was the solution. By setting the Froude number of the model and the prototype equal to each other, it was simple to find the speed of the prototype because the other three variables were known. After obtaining a speed of 10.22 m/s for *Caitlyn*, the existing numbers could be plugged back into the Froude number equation. Because they both received the same value of 0.24, it can be determined that the ships undergo Froude similarity.

Next, the Reynold's numbers could be calculated. Here, the kinematic viscosity was based off of an educated assumption. The locations of both ships had to be assumed in order to find the temperature of the water, and therefore kinematic viscosity. It was assumed that the DFDS *Corona Seaways* was in Antwerp and the TVS *Caitlyn* was in Gothenburg. Even though both ships will not necessarily be going the high speeds in these locations, temperatures could be recorded that would be similar to those used in other model testings. By using this method, it was determined that the temperature of the model was 10 degrees Celsius and the prototype temperature was 8.89 degrees Celsius. Seawater tables were then used in order to determine the kinematic viscosity at any temperature. Obtaining these values was essential to finding the Reynold's number of both ships.

The following step required information from the Technical University of Denmark's Project no 2010-56, *Prediction of Resistance and Propulsion Power of Ships*. Appendix I has graphs of Froude's number versus residual resistance for bulky ships (with a prismatic coefficient greater than 0.7). The first graph on page 48 was used because *Caitlyn's* L/volume$^{1/3}$ ratio was 6.0. By lining up the calculated Froude number with the point of the ship's prismatic coefficient (0.86), a 3.5×10^{-3} C_R value was determined. This graph is given in Figure 22.

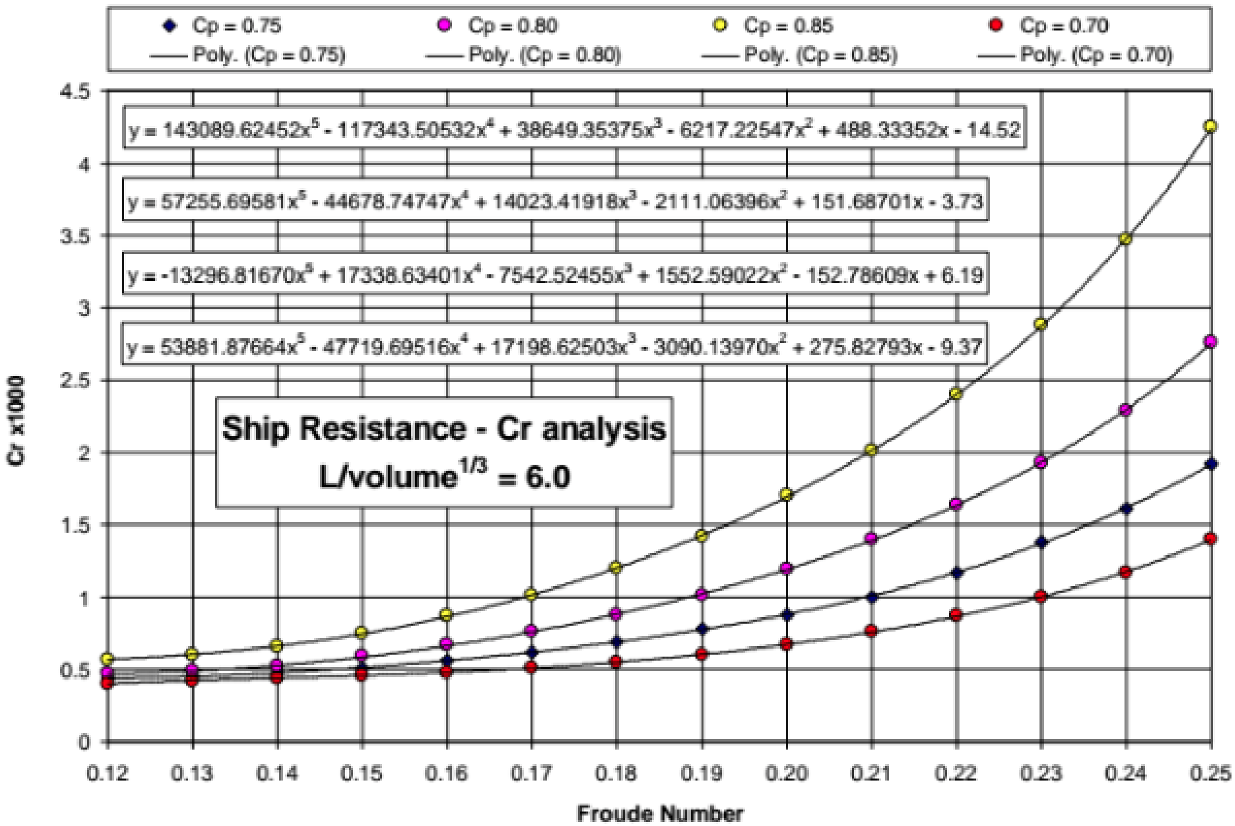

Figure 22: Froude Number vs. Residual Resistance

The C_F of both ships was calculated by using the ITTC 1957 formula. Additionally, in ship resistance model testing, C_R of the model and C_R of the prototype are the same. These two values of the model were then added to find C_{Tm}. Similarly for C_{Tp}, a roughness allowance was added into this calculation as well. From here, the total resistance and EHP of the vessels could be calculated. The values for all of these results were tabulated in Table 17.

Table 17: Ship Resistance Calculations

Details	Model	Prototype
Length (m)	187.06	185
Water Temperature (C)	10	8.89
Density (kg/m^3)	1030.106	1030.299
Kinematic Viscosity (m^2/s)	1.31E-06	1.35E-06
Wetted Surface (m^2)	6654.76	6509.16
Roughness Allowance		4.00E-04
Speed (m/s)	10.28	10.22
Fr	0.24	0.24
Re	1471290589	1396381093
Cr	3.50E-03	3.50E-03
Cf	1.46E-03	1.47E-03
Ct	4.96E-03	5.37E-03
Rt	1796940	1880764
EHP	24772.0842	25776.3284

8.2. Ship Powering and Propulsion System (Written by Christopher Williams)

By looking at the parent ship, the engines chosen were Man B&W 6S60ME engines. Upon looking at the Man B&W website, using the same engines will be advantageous because of the efficiency and the low emissions produced. This engine is a straight 6 cylinder, super long stroke, 2 stroke engine. This power plant is efficient and only consumes 173 grams of fuel per kilowatt in an hour. Looking at the amount of kilowatts required to power *Caitlyn*, the fuel consumed in an eleven-hour journey would be around 1,100 cubic meters. At this rate, with a 4,475 cubic meter tank, the vessel will be able to run multiple transatlantic trips before refueling. This will decrease the operation cost and increase profit. Along with being efficient, the engines are also clean burning. By using multiple filters, including a urea filter, the engines produce a NO_x level below the maximum amount set by MARPOL and SOLAS. The other emissions produced by the engines are also below the maximum amount allowed by MARPOL and SOLAS regulations.

9. Conclusion (Written by Zachary Gonzales)

Upon completion of the concept design of a reliable, efficient, and environmentally friendly Panamax Ro-Ro vessel optimized for transatlantic voyages, it was determined that the solution was indeed possible. With maximum optimization, TVS *Caitlyn* will make the voyage from the Port of Gothenburg, Sweden to the Port of Galveston, Texas in 10 days 17 hours carrying 1,702 Volvo automobiles and 1,080 TEUs. She will displace 29,442 tonnes when fully loaded, and will sail at 21 knots to meet schedule, all while flying the American flag. The comprehensive concept design has proved to be a viable replacement for four of Rotto Nordic Lines' aging Ro-Ro vessels.

There were many challenges faced when working through the iterations of the conceptual design. Figure 23 shown below loosely represents the design path followed by Transglobal Vehicular Solutions as the concept design for TVS *Caitlyn* was conceived.

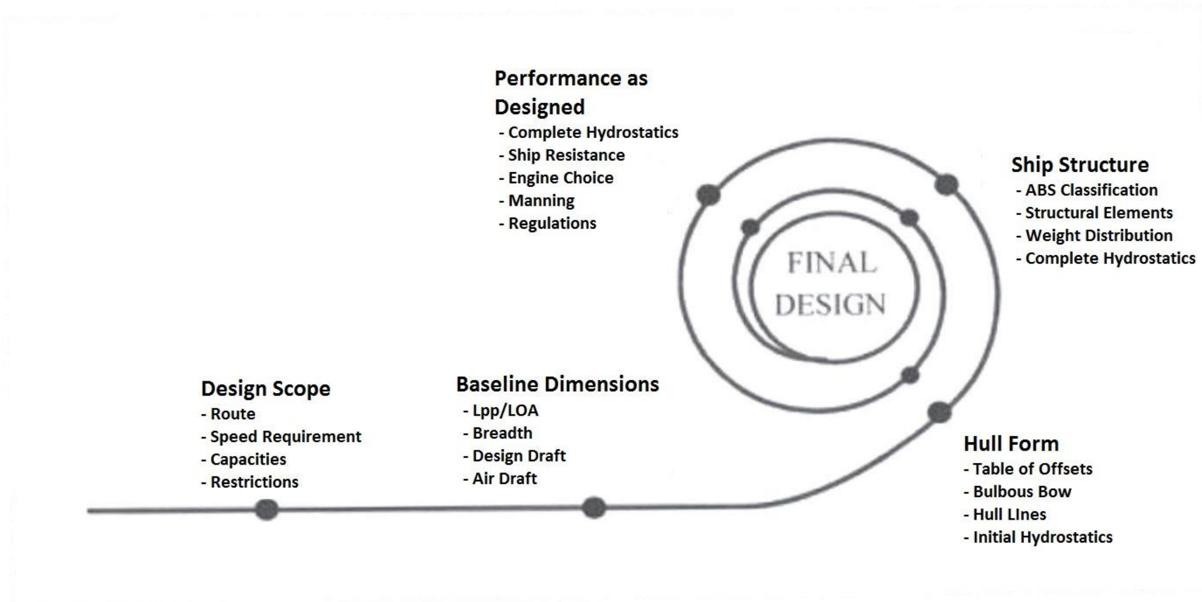

Figure 23: Final Design

The design team thoroughly enjoyed the opportunity to design such a vessel and completely acknowledges the fact that a more intensive design process is called for in order for the concept design to move forward. In the design's current state, TVS *Caitlyn* meets or exceeds all customer specifications regarding the vessel itself and voyage specifics. She also meets strict classification standards provided by the American Bureau of Shipping regarding her hull and deck structures, and she closely adheres to all IMO regulations.

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11. Appendix

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